# Navigation and Guidance for the Mars Surveyor '98 Mission

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## Extended Abstract

Introduction

In December, 1998 and January 1999 NASA will launch two spacecraft to Mars as part of the overall Mars Exploration Program managed at JPL. One is an orbiter that will arrive at Mars in October of 1999 carrying a science payload for remote sensing. Once safely inserted into an elliptical capture orbit about Mars, the orbiter will immediately begin aerobraking to achieve a circular mapping orbit at an altitude of 405 km. In December of 1999, the second of the two spacecraft, a lander, will touch down on the layered terrain of the Martian southern hemisphere, and begin examining the surface (and beneath the surface) for evidence of water and other volatiles. The lander also carries imaging equipment to observe the landing site during descent as well as aster landing.

The two spacecraft pose interesting navigation challenges during the interplanetary cruise phase. The orbiter needs to be delivered to Mars with an error in periapsis altitude no greater than 20 km. The lander's delivery requirements are tighter still: The flight path angle error upon atmosphere entry is to be no larger that 0.25 degrees. This is one-fourth of the error tolerance for the Mars Pathfinder mission, the last mission to successfully land on Mars. This paper discusses the strategy developed to satisfy the navigation requirements for both spacecraft.

Sources of Error in Orbit Determination

The ground-based navigation system supporting both spacecraft must deal with a variety of error sources affecting both the flight path and the tracking data. Those error sources affecting flight path include injection from the launch vehicle, solar radiation pressure, midcourse maneuvers, and plantary gravity and ephemeris. Furthermore, the lander's design incorporates a 3-axis stabilized attitude control system of four unbalanced thrusters which results in thruster firings (and resultant delta-V) every 20-80 minutes. This particular error source is expected to be a significant contributor to the overall guidance error. Therefore, a strategy has been developed to capture actual thruster firing data from the lander and relay it to the ground stystem, where an accurate model of the Delta-V contributions can be formulated and included in the flight path computation. A stochastic acceleration model will be used in the orbit determination filter to determine the remaining Delta-V error. While the orbiter has reaction wheels for attitude control, it too will incur Delta-V contributions from momentum wheel desaturation maneuvers, expected to be needed every 1-2 weeks.

Tracking Data

Error sources affecting the tracking data are of equal importance in orbit determination. If all such errors are not properly accounted for, any mismodelings may manifest themselves as incorrect changes in the flight path estimate. Furthermore, this incorrect flight path estimate would also carry too small an uncertainty, leading the navigation team to believe the estimate's error is smaller than it might actually be. Sources of error affecting the data include the locations of the DSN stations on the surface of Earth, the orientation and rotation model for the Earth, Earth and Mars ephemeris, tropospheric delay, ionospheric delay and solar plasma. Furthermore, biases (both constant and stochastic) may be present in the range data, caused by either the onboard transponder delays or ground station delay.

The navigation system for the orbiter and lander relies on Doppler and range measurements collected by NASA's Deep Space Network to monitor and estimate the orbit of each spacecraft. These data are collected at X-band in coherent mode, resulting in very precise measurements of both range and range rate. For pre-launch analysis, the measurement noise are assumed to be equivalent to what was observed in Mars Pathfinder and Mars Global Surveyor tracking data, specifically 0.05 mm/second and 0.5 meters for Doppler and range measurements, respectively. Due to power and thermal control limitations, each spacecraft's transponder can be on no longer than 4 hours, followed by an 'off' period proportional to the preceding 'on' period. Therefore, radiometric tracking data from each spacecraft is only available 44% of the time (on average). This contrasts with previous Mars missions which did not have this limitation, and therefore could afford nearly continuos tracking data.

## Near-Simultaneous Tracking Technique

Because the orbiter arrives first and ends its aerobraking some time before the lander arrives, an opportunity exists to combine tracking data from the orbiter with tracking data from the lander (during its approach to Mars) and simultaneously estimate the state of both spacecraft in one orbit determination filter. In doing so, the resulting uncertainty of the lander's predicted state is much smaller than if only lander tracking data were utilized. This somewhat non-intuitive results happens because both spacecraft are tracked from identical stations on Earth, and therefore share common error sources such as station locations, Earth orientation, Earth rotation, troposphere, ionosphere and solar plasma. Furthermore, sensitivity to the error in the Martian ephemeris is reduced since the filter can readily obtain an accurate estimate of the Martian ephemeris from the orbiter's tracking data. This technique of combining the tracking data from the lander with that of the orbiter (or the Mars Global Surveyor spacecraft also in orbit about Mars) has been dubbed 'Near Simultaneous Tracking', and is the baseline plan for precisely navigating the lander to its entry coordinates. As a validation of this technique, a short demonstration of its usefulness was performed with actual data from Mars Pathfinder and Mars Global Surveyor shortly before the MGS arrival at Mars in the Fall of 1997.

## Results

Orbit determination and guidance analysis performed at the Jet Propulsion Laboratory in support of mission planning has shown that with the above mentioned error assumptions and the near simultaneous tracking technique will result in an expected guidance error that meets mission requirement for both spacecraft. Figures 1 and 2 illustrate the expected guidance errors in the interplanetary aiming plane (or B-plane). These figures also show the areas within the B-plane that satisfy the navigation requirements for each spacecraft, and clearly illustrate that the capability provided by the planned navigation strategy will satisfy the requirements.

Another product of navigation analysis is an estimate of the required delta-V needed for midcourse maneuvers. This data is obtained from a Monte-Carlo simulation of the interplanetary cruise phase, using assumptions in launch vehicle injection error, maneuver execution error, and orbit determination error prior to each maneuver. Statistical data of required Delta-V are available for each maneuver and for all five maneuvers combined. These results have determined the quantity of propellant needed to obtain a 95% probability of successfully completing the interplanetary cruise phase for both spacecraft.

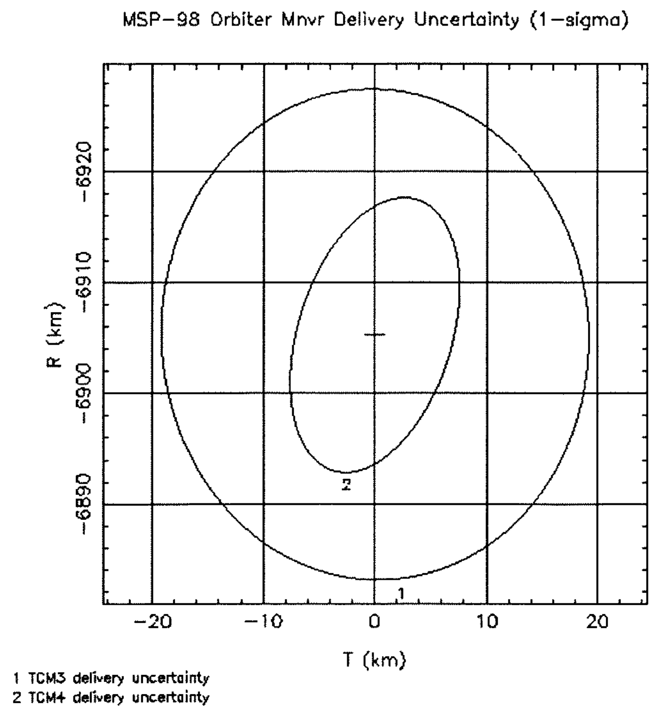


**Figure 1: Guidance error results (1-σ) for the orbiter, mapped in the Martian B-plane**

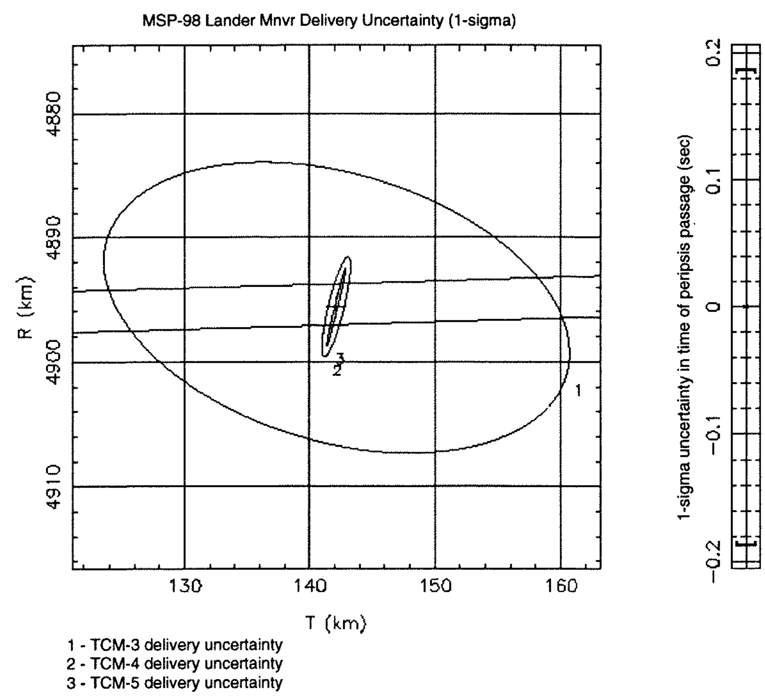


**Figure 2: Guidance error results (1-σ) for the lander, mapped to the Martian B-plane**